HEAT TRANSFER ANALYSIS OF AUTOMOTIVE DISC BRAKES

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ABSTRACT

The braking system plays the crucial role in the safety of a vehicle and its design poses a critical challenge. The heat dissipation and thermal performance of ventilated brake discs strongly depends on the aerodynamic characteristics of the air flow through the rotor passages. In this paper, the 3D CAD models for Solid disc and discs with different fin configurations namely, Straight Elliptical fins, Backward curved fins and Forward curved fins are designed. Each finned model disc with 12, 24 and 36 number of fins were developed using catia V5R20. The 3D FE models have been developed for the above disc configurations using Hypermesh V11 and the heat transfer analysis was carried out using ansys fluent13 at two different velocities at 40 mph and 50 mph. It was found that the Forward curved fins are having superior thermal performance characteristics both at 40 and 50 mph, namely at 40 mph and with 36 fins, show surface Heat Transfer coefficient 278.2 w/m^{2}k, Nusselt number 11000, Reynolds number 1930.

Keywords: Brake rotor, C.F.D., Heat transfer, Numerical Simulation, Velocity.

I. INTRODUCTION

The disc brake is a wheel brake which slows rotation of the wheel by the friction caused by pushing brake pads against a brake disc with a set of calipers. The brake disc (or *rotor* in American English) is usually made of cast iron, but may in some cases be made of composites such as reinforced carbon–carbon or ceramic matrix composites. This is connected to the wheel and/or the axle. To stop the wheel, friction material in the form of brake pads, mounted on a device called a brake caliper, is forced mechanically, hydraulically, pneumatically or electro magnetically against both sides of the disc. Friction causes the disc and attached wheel to slow or stop. Brakes convert motion to heat, and if the brakes get too hot, they become less effective, a phenomenon known as brake fade.

For solid rotors, the highest temperature occurs on the surfaces of the rotors. To decrease the maximum temperature, the most effective way is to increase the thickness of the rotors. However, the increase is limited by the pistons. Materials also have effects on the rotor's temperature. From this research, steel is a better alloy to dissipate heat from the rotors. But in practical design problems, the thermal performance is not the only requirement. From the perspective of stiffness, friction resistance and cost, the cast iron material is common used in industry.

The objective of current paper is

- To estimate heat flux generated in solid discs
- The combinations of various fin configurations namely Straight Elliptical, Backward Curved, Forward curved and the various numbers of fins (12, 24 and 36) at two different speeds (40 and 50 mph) will be studied.
- To predict the effect of these variables on the heat transfer performance of disc brakes.

The technical drawing of rotor is as shown in Fig1.

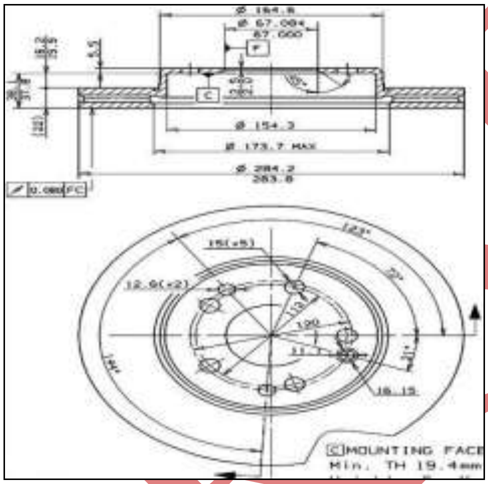

Fig.1 Drawing of OEM XYZ Rotor

II. METHODOLOGY

The 3D CAD models were developed for various disc configurations, namely Solid disc, discs with Straight elliptical fins, Backward curved fins and Forward curved fins with 12, 24 and 36 fins were created using CATIA V5R20. The 3D FE models were created for the above mentioned disc configurations using HYPERMESH V11. The conjugate heat transfer analysis was carried for each disc model using ANSYS-FLUENT13 at a disc speed of 40 mph and 50mph. The result plots were taken using ENSIGHT post processor. The cad models of rotors are shown in Fig2,3,4 and 5.

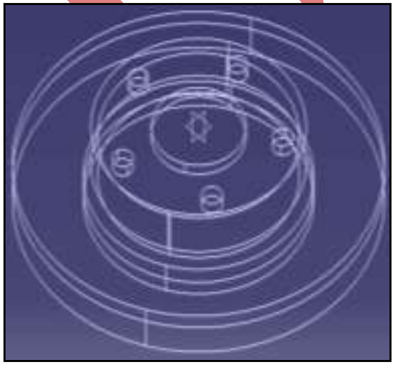

Fig.2 Solid Rotor

Fig.3 Rotor with Straight Elliptical Fins

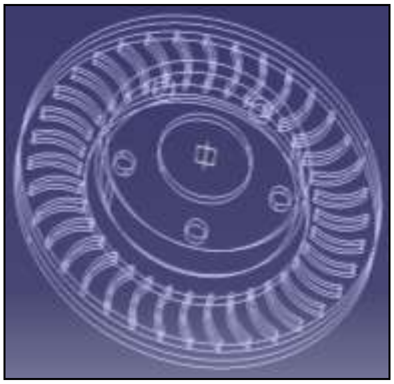

Fig.4 Rotor with Backward Curved Fins

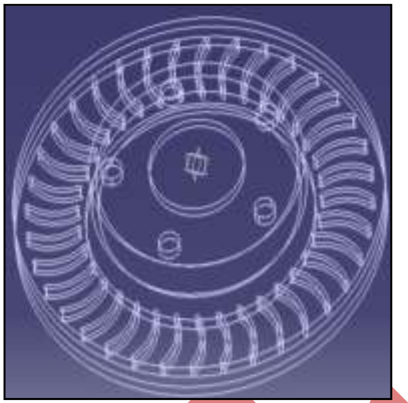

Fig.5 Rotor with Forward Curved Fins

III. PROPERTIES OF MEDIUM

In this section the various thermal and mechanical properties of the brake material and air medium will be presented.

Cast Iron Properties	Air Properties
Thermal conductivity, k = 27-46 w/m-K	Heat transfer coefficient, h = 5-25 w/m^2-K (Free Convection)
Density, ρ = 6800-7800 kg/m^3	25-200 w/m^2-K (Forced Convection)
Specific heat, c = 460 J/Kg-K	

Table.1 Properties of Medium

The vehicle and brake disc specifications considered for the analysis will be tabulated.

Vehicle Specifications	Disc Brake Specifications
Manufacturer = OEM	Brake Disc Thickness (mm): 21.9
Model = OEM XYZ	Brake Disc Type: Vented Disc
Year of Manufacture = 1998	Centering Diameter (mm): 67.0
Curb weight = 1600 Kg	Fitting Position: Front Axle
	Height (mm): 48.2
	Minimum Thickness (mm): 20.0
	Number of Holes: 5
	Outer Diameter (mm): 262.4

Table.2 Vehicle specifications

IV. BOUNDARY CONDITIONS

Inlet: Pressure at atmospheric condition (101325 Pa)

Outlet: Pressure at slightly above atmospheric condition (101525 Pa)

Ambient Temperature: 300 K

Convergence Tolerance: Default

Velocity of Rotor: 40 and 50 mph

For this problem, the model is based on the following assumptions:

- Continuum flow
- Newtonian fluid
- Steady state
- Laminar flow
- Constant properties (density, conductivity, specific heat, and viscosity
- Uniform surface heat flux
- Gravitational effect is considered.

The following commands/options were used in ANSYS-FLUENT to do the flow analysis.

- Pressure based solver
- Velocity formulation - Absolute
- Gravity is applied
- Second-Order upwind scheme for flow
- Convergence checks for continuity, energy and Momentum are taken as default values (1e-6)
- Energy equation is on.
- K-e (K-epsilon) model with standard wall functions
- Coupled (Pressure-velocity coupling) solver

V. VARIOUS PLOTS FOR ALL GEOMETRIES

In this Chapter, the results for 1 model of Solid disc and 3 models of discs with different fin shapes, namely Straight Elliptical fins, Backward curved fins, and Forward curved fins at different speeds, namely 40 mph and 50 mph with 12, 24 and 36 number of fins are presented.

The variation of Heat Transfer Coefficient with respect to number of fins, for various fin shapes at 40mph is shown in Fig.6

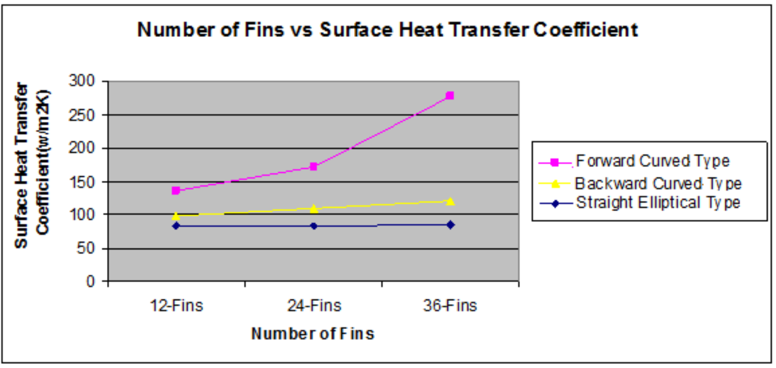

Fig.6 Number of Fins vs. Surface Heat Transfer Coefficient

From Fig.6 it is observed that the Heat Transfer Coefficient is increasing as the numbers of fins are increasing from 12 to 24 and 24 to 36. From Fig.6 it is clear that the Forward curved fins with 36 numbers of fins are having highest Heat transfer coefficient compared to the rest.

The values of Heat Transfer coefficient for Solid disc and discs with different fin shapes namely Straight elliptical fins, Backward curved fins and Forward curved fins for 12 fins, 24 fins and 36 fins at 40mph and 50 mph are shown in the Table 3.

Fin Shape	Number of Fins	Surface Heat Transfer Coefficient (w/m2-K) at 40mph	Surface Heat Transfer Coefficient (w/m2-K) at 50 mph
Solid		78.2	97.75
Straight Elliptical Fins	12-Fins	82.6	103.25
	24-Fins	83.96	104.95
	36-Fins	85.49	106.86
Backward Curved Fins	12-Fins	97.98	122.48
	24-Fins	108.66	135.83
	36-Fins	120.24	150.3
Forward Curved Fins	12-Fins	136.29	170.36
	24-Fins	171.73	214.66
	36-Fins	278.2	347.74

Table.3 Values of Heat Transfer Coefficient at 40mph and 50 mph

The variation of Surface Nusselt Number with respect to number of fins, for various fin shapes at 40mph is shown in Fig.7

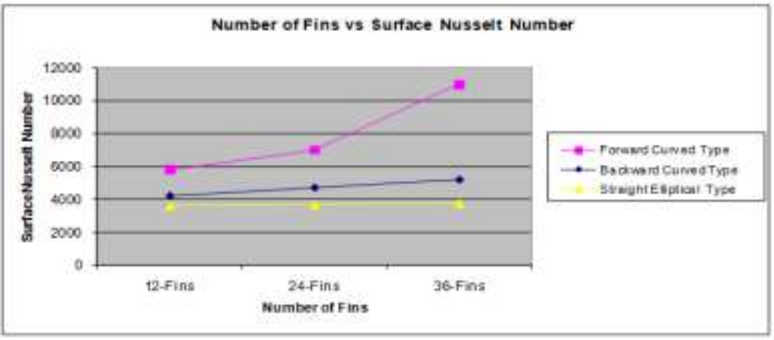

Fig.7. Number of Fins vs. Nusselt Number

From Fig.7 it is observed that the Nusselt Number is increasing as the numbers of fins are increasing from 12 to 24 and 24 to 36. From Fig.7 it is clear that the Forward curved fins with 36 numbers of fins are having highest Nusselt Number compared to the rest.

The values of Nusselt Number for Solid disc and discs with different fin shapes namely Straight elliptical fins, Backward curved fins and Forward curved fins for 12 fins, 24 fins and 36 fins at 40mph and 50 mph are shown in the Table 4

	Number of Fins	Surface Nusselt Number at 40mph	Surface Nusselt Number at 50 mph
Solid		3230	4038
Straight Elliptical Fins	12-Fins	3620	4525
	24-Fins	3680	4600
	36-Fins	3752	4690
Backward Curved Fins	12-Fins	4215	5269
	24-Fins	4712	5890
	36-Fins	5213	6516
Forward Curved Fins	12-Fins	5814	7268
	24-Fins	7000	11640
	36-Fins	11000	15784

Table.4 Values of Nusselt Number at 40mph and 50 mph

The variation of Reynolds Number with respect to number of fins, for various fin shapes at 40mph is shown in Fig.8

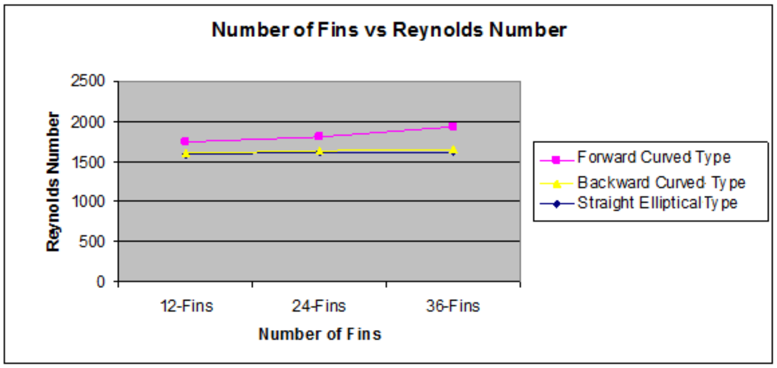

Fig.8 Number of Fins vs. Reynolds Number

From Fig.8 it is observed that the Reynolds Number is increasing as the numbers of fins are increasing from 12 to 24 and 24 to 36. From Fig.8 it is clear that the Forward curved fins with 36 numbers of fins are having highest Reynolds Number compared to the other.

The values of Reynolds Number for Solid disc and discs with different fin shapes namely Straight elliptical fins, Backward curved fins and Forward curved fins for 12 fins, 24 fins and 36 fins at 40mph and 50 mph are shown in the Table 5

Fin Shape	Number of Fins	Reynolds Number at 40mph	Reynolds Number at 50 mph
Solid		1422	1582
Straight Elliptical Fins	12-Fins	1602	1730
	24-Fins	1628	1742
	36-Fins	1656	1787

Backward Curved Fins	12-Fins	1602	1826
	24-Fins	1628	1859
	36-Fins	1656	1902
Forward Curved Fins	12-Fins	1739	1915
	24-Fins	1812	2095
	36-Fins	1930	2313

Table.5 Values of Reynolds Number at 40mph and 50 mph

Tables 3,4 and 5 shows the results of heat transfer analysis for 1 model of Solid disc and 3 models of discs with different fin shapes, namely Straight Elliptical fins, Backward curved fins, and Forward curved fins at different speeds, namely 40 mph and 50 mph with 12, 24 and 36 number of fins.

From the tables 3,4 and 5 it is observed that as the number of fins are increased for curved rotors the heat transfer parameters like Heat transfer coefficient, Nusselt number, and Reynolds number are increasing.

It is also observed that these heat transfer parameters are changing with the change of curvature of fins. These parameters are increasing from Straight elliptical fins to Backward curved fins and Backward curved fins to Forward curved fins.

VI. CONCLUSION

The following conclusions have been drawn from the analysis performed on the various fin configurations at 40 and 50 mph. The most important variables affecting thermal performance are fin numbers and curvature. From the result the disc with Forward type fins is superior in terms of heat transfer performance when compared to all other fin types, namely Solid disc, Backward curved fins and Straight elliptical fins. It is found that at 40mph and 50mph the disc with Forward curved fins is having the better heat transfer characteristics. Forward disc has the following values at 40mph with 36 numbers of fins Surface Heat Transfer Coefficient 278.2 (w/m^2-K), Nusselt Number 11000, and Reynolds Number 1930.Forward disc has the following values at 50mph with 36 numbers of fins Surface Heat Transfer Coefficient 347.74 (w/m^2-K), Nusselt Number 15784, and Reynolds Number 2313.From the results it is observed that as the speed of the rotor increases Reynolds number increases, Nusselt number improved and Heat transfer coefficient increased.

REFERENCES

[1]. D. A. Johnson, B. A. Sperandei, R. Gilbert, Analysis of the Flow Through Vented Automotive Brake Rotor, Journal of Fluids Engineering, ASME, Nov. 2003,Vol. 125/979

[2]. J. H. Choi, I. Lee, Finite Element Analysis of Transient Thermo elastic Behaviors in Disk Brakes, Science Direct, Wear 257 (2004) 47-58.

[3]. D. G. Grieve, D. C. Barton, D. A. Crolla, J. T. Buckingham, Design of a lightweight Automotive Brake Disc Using Finite Element and Taguchi Techniques, Institution of Mechanical Engineers; 1998; 212, 4; ProQuest Science Journal.

[4]. Z. Chi, Y. He and G. F. Naterer, Geometrical Optimization of Vented Brake Discs of Automotive Vehicles, submitted to CATS 2008, Toronto, Canada, 2008

[5]. Z. Chi, G. F. Naterer and Y. He, Thermal Performance Analysis of Vented Automotive Brake Discs, CSME Forum 2008, University of Ottawa, Ottawa,Canada, 2008.

[6]. D. G. Grieve, D. C. Barton, D. A. Crolla, J. T. Buckingham, Design of a lightweight Automotive Brake Disc Using Finite Element and Taguchi Techniques, Institution of Mechanical Engineers; 1998; 212, 4; ProQuest Science Journal.

[7]. S. Aus Der Wiesche, Heat Transfer from a Rotating Disk in a Parallel Air Cross flow, International Journal of Thermal Sciences 46(2007) 745-754.

[8]. Z. Chi, G. F. Naterer and Y. He (2008) Effects of Brake Disc Geometrical Parameters and Configurations on Automotive Braking Thermal Performance, CSME Transactions 2008, University of Ottawa, Ottawa, Canada, 2008

[9]. A. D. Mcphee and D. A. Johnson, Experimental Heat Transfer and Flow Analysis of a Vented Braked Brake Rotor, International Journal of Thermal Sciences, Vol. 3, No. 6, 2007.

[10]. M. Naji, M. Al-Ninr, S.Masoud, Transient thermal behavior of a cylindrical brake system, Heat and Mass Transfer 36 (2000) 45-49, Springer-Verlag 2000.

[11]. Bejan, Adrian, Convection heat transfer, 3rd edition. Hoboken, N.J.:Wiley,c2004.

[12]. Latif M. Jiji, Heat Convection, Berlin ; New York : Springer, c2006

[13]. Brake Design and Safety, 2E, Rudolf Limpert